Flask-to-Field Efforts for Non-PRASA Water Sustainability

Sangchul Hwang, PhD
Professor
Department of Civil Engineering
UPR-Mayagüez

Sep. 11, 2014

Hwang Water Quality Laboratory

Synopsis

- Non-PRASA Systems
  - Location and status
- Effort 1: GIS-based Multi-Criteria Decision Analysis
  - Who needs more help?
  - 1st Rural (Non-PRASA) Community Water Supply and Sanitation Workshop
- Effort 2: Telemetry Monitoring
  - Field-scale remote water quality monitoring of a Non-PRASA System
  - Lab-scale scientific research
- Effort 3: Source Water Quality Monitoring
  - Physicochemical and bacteriological analysis
- Effort 4: Drum Filtration / Disinfection Unit
  - Field-scale solar-powered unit
  - Lab-scale scientific research
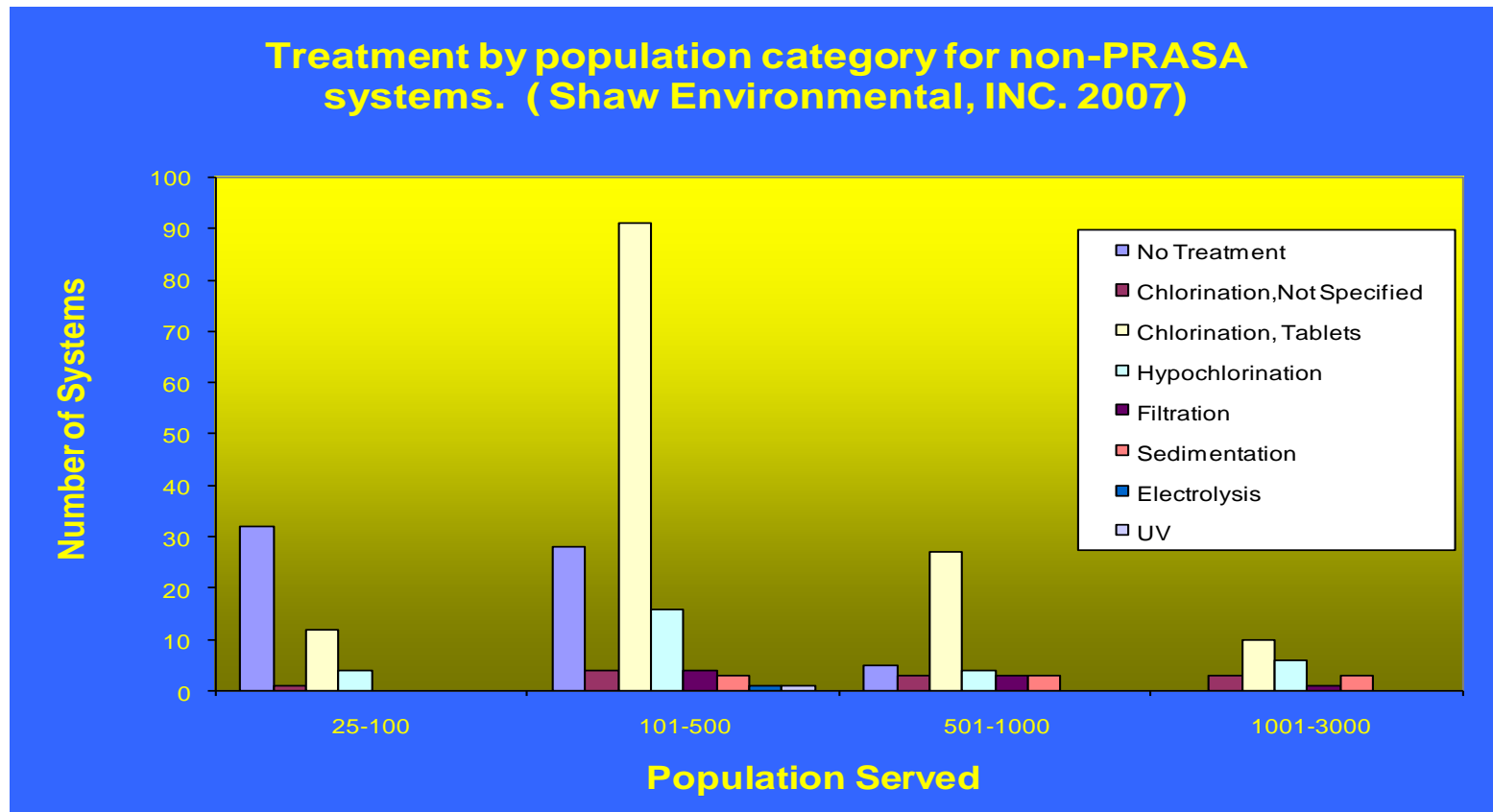
Location of Non-PRASA Systems

- Mostly in the center, mountainous rural area
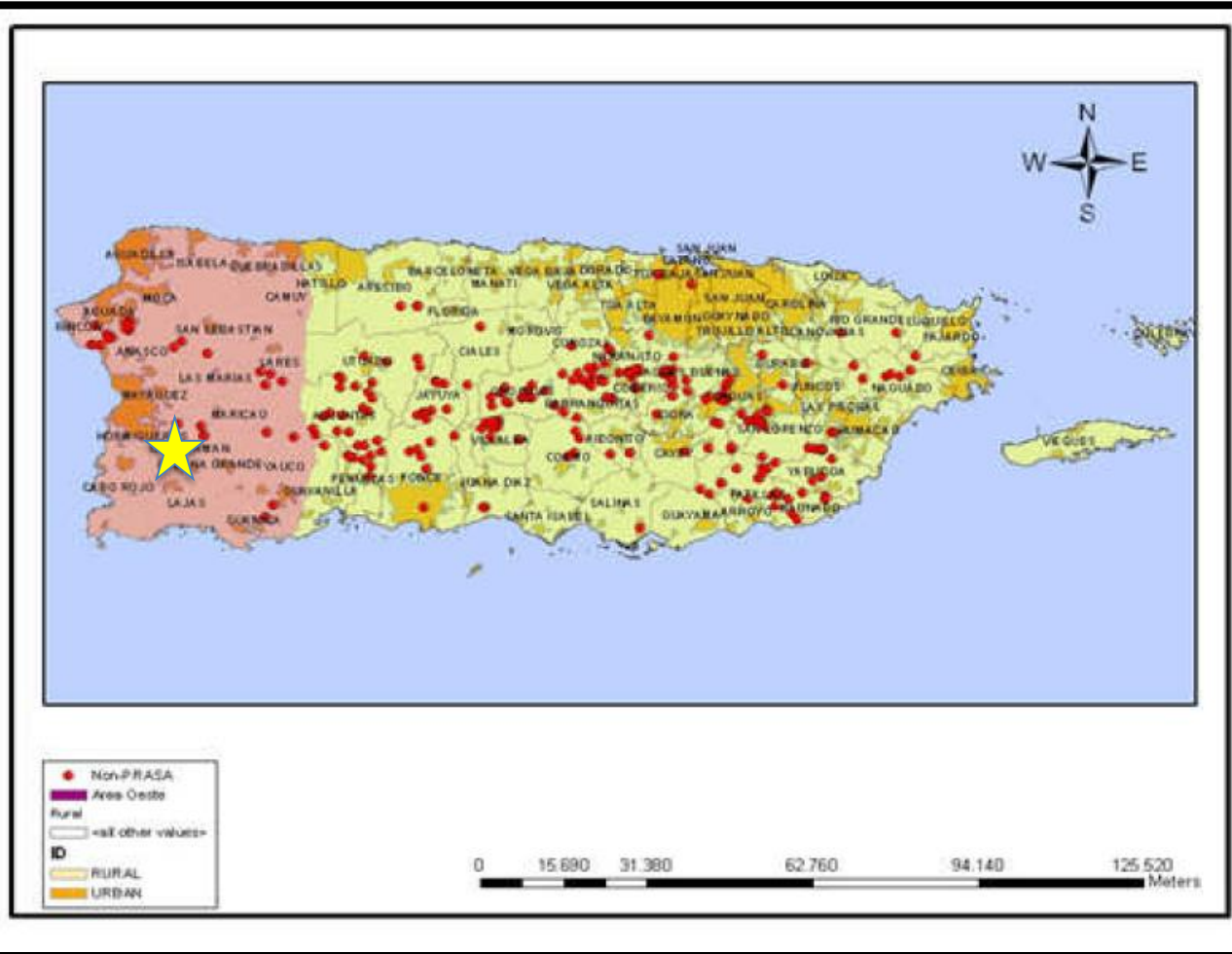
Rio Piedras community in San German

Status of Non-PRASA Systems

- ~240 systems in Puerto Rico (~126,000 people)
- 95% of them do not comply with bacteriological standards (as of Yr 2008)
- Of Non-PRASA systems serving a population <100, >60% has no treatment

Treatment by population category for non-PRASA systems. (Shaw Environmental, INC. 2007)

Legend: No Treatment; Chlorination, Not Specified; Chlorination, Tablets; Hypochlorination; Filtration; Sedimentation; Electrolysis; UV

Number of Systems vs Population Served (25-100, 101-500, 501-1000, 1001-3000)

EFFORT 1.
GIS-BASED MULTI-CRITERIA DECISION ANALYSIS

GIS-based Multi-Criteria Decision Analysis

- Western Puerto Rico
  - 7 municipalities
  - 27 Non-PRASA Systems

- Multi-criteria
  - Population density (rural vs. urban)
  - Type of treatment
  - Status of treatment
  - Bacteriological quality
  - Infant mortality
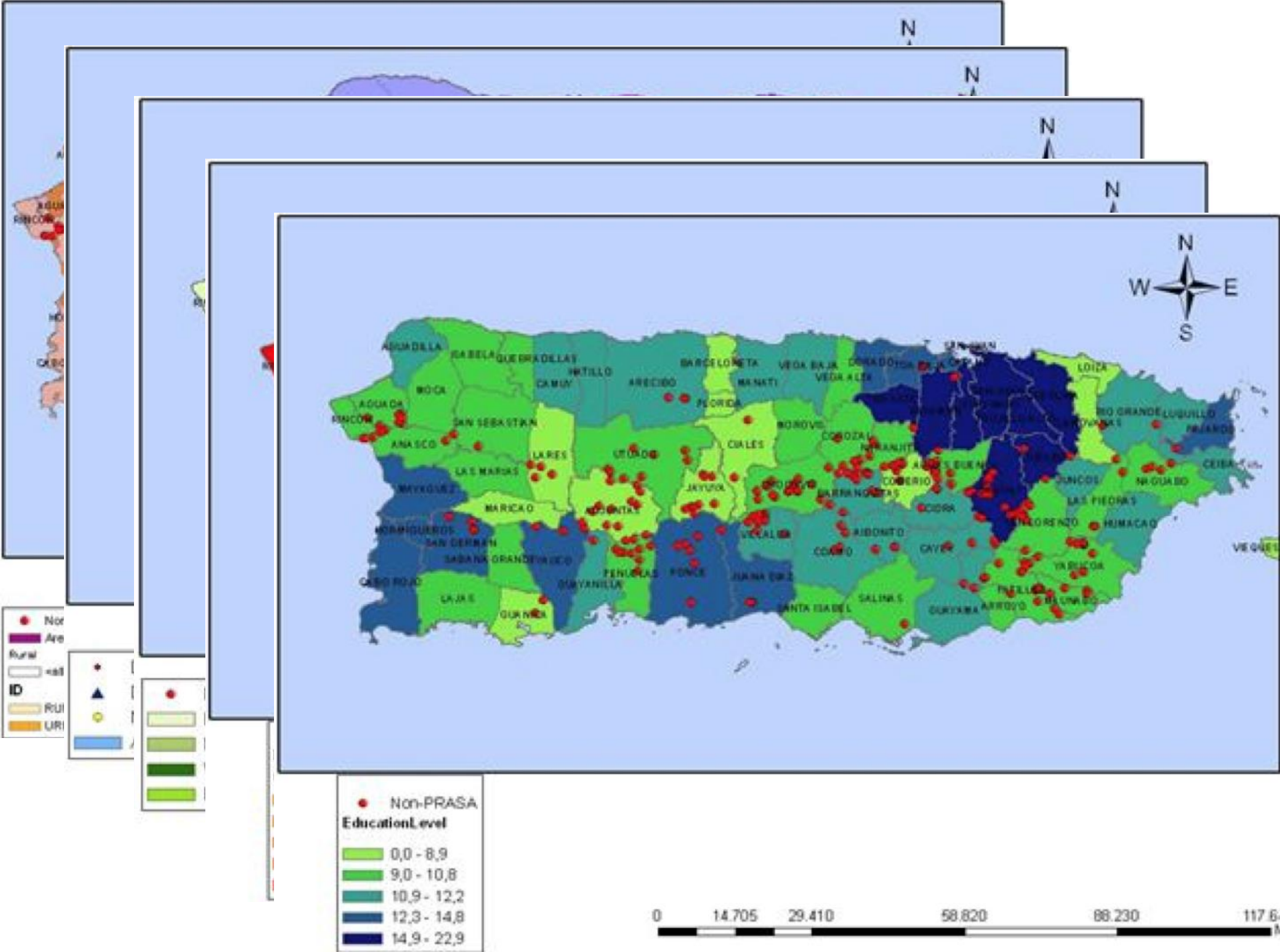 - Cancer rate
  - Education level

Data sources:
- DoH, EPA, USGS, PRASA
- First Rural (Non-PRASA) Community Water Supply and Sanitation Workshop

First Rural (Non-PRASA) Community Water Supply and Sanitation Workshop

- Feb 25, 2008
- Topics
  - Perspective of rural (Non-PRASA) community water supply and sanitation,
  - Status of rural water supply and sanitation systems, and
  - Public policies and best management practices.
- Speakers
  - Carl Soderberg (EPA)
  - Javier Velez (DRNA)
  - Carlos Lopez (EQB)
  - Irma Lopez (PRASA)
  - Javier Torres (DoH)
  - Pedro Diaz (USGS)
  - Jorge Rivera (PRWRERI)
 - Ingrid Padilla (UPRM)
  - Luisa Seijo (IUDC)

Non-PRASA
EducationLevel
- 0,0 - 8,9
- 9,0 - 10,8
- 10,9 - 12,2
- 12,3 - 14,8
- 14,9 - 22,9

0   14.705   29.410   58.820   88.230   117.6

AGUADA	RURAL	EDUCATION	CANCER	INFANT MORTALITY	TYPE OF TREAT.	THE SYST.	BACTERIOLOGICAL QUALITY	QUALIFICATION
Jaguey Chiquito	1	8	1	5	5	5	10	35
Cerro Gordo Arriba II	10	8	1	5	5	1	10	40
Cerro Gordo	1	8	1	5	5	5	1	26
Comunidad Aislada Desarrollo	10	8	1	5	5	5	10	44
Comunidad Cerro Gordo El Parque	10	8	1	5	5	0	10	39
Quebrada Larga	10	8	1	5	5	1	1	31
Proyecto Aguas	10	8	1	5	5	1	1	31
ANASCO								
Caguabo	10	8	2	1	5	5	10	41
Comunidad Hatillo	10	8	2	1	5	5	1	32
Pinales Arriba	10	8	2	1	5	5	1	32
Corcobada	10	8	2	1	5	5	10	41
SAN SEBASTIAN								
Sonador II	10	8	1	1	5	1	1	27
Acueducto Rural Guacio Inc	10	8	1	1	5	1	10	36
LARES								
Vega Acevedo	10	10	1	1	5	1	10	38
Com. Las Cuarenta	10	10	1	1	5	5	1	33
Lucas Lugo	10	10	1	1	10	5	10	47
SAN GERMAN								
Rosario Penon	10	4	2	1	5	5	1	28
Comunidad Mendez	10	4	2	1	10	5	1	33
Periche	10	4	2	1	5	5	10	37
Comunidad RioPiedras	10	4	2	1	1	1	10	29
YAUCO								
B. Rubias	10	4	2	10	5	5	1	37
Guaraguao	10	4	2	10	1	1	1	29
La Montana	10	4	2	10	1	10	10	47
La Jurada	10	4	2	10	10	10	10	56
Mongote	10	4	2	10	10	0	1	37
MARICAO								
Aceitunas	10	10	1	5	10	5	1	42
Llanadas	10	10	1	5	10	10	1	47

No.	NON-PRASA SYSTEM	MUNICIPALITY	RANK
1	La Jurada	Yauco	1
2	Lucas Lugo	Lares	2
3	Llanadas	Maricao	2
4	La Montana	Yauco	2
5	Comunidad Aislada Desarrollo	Aguada	5
6	Aceitunas	Maricao	6
7	Corcobada	Añasco	7
8	Caguabo	Añasco	7
9	Cerro Gordo Arriba II	Aguada	9
10	Comunidad Cerro Gordo El Parque	Aguada	10
11	Vega Acevedo	Lares	11
12	B. Rubias	Yauco	12
13	Periche	San Germán	12
14	Mongote	Yauco	12
15	Acueducto Rural Guacio Inc	San Sebastian	15
16	Jaguey Chiquito	Aguada	16
17	Comunidad Mendez	San Germán	17
18	Com. Las Cuarenta	Lares	17
19	Comunidad Hatillo	Añasco	19
20	Pinales Arriba	Añasco	19
21	Quebrada Larga	Aguada	21
22	Proyecto Aguas	Aguada	21
23	Guaraguao	Yauco	23
24	Comunidad RioPiedras	San Germán	23
25	Rosario Penon	San Germán	25
26	Sonador II	San Sebastian	26
27	Cerro Gordo	Aguada	27

EFFORT 2.
TELEMETRY OF RIO PIEDRAS COMMUNITY WATER

Telemetry of Rio Piedras Community Water
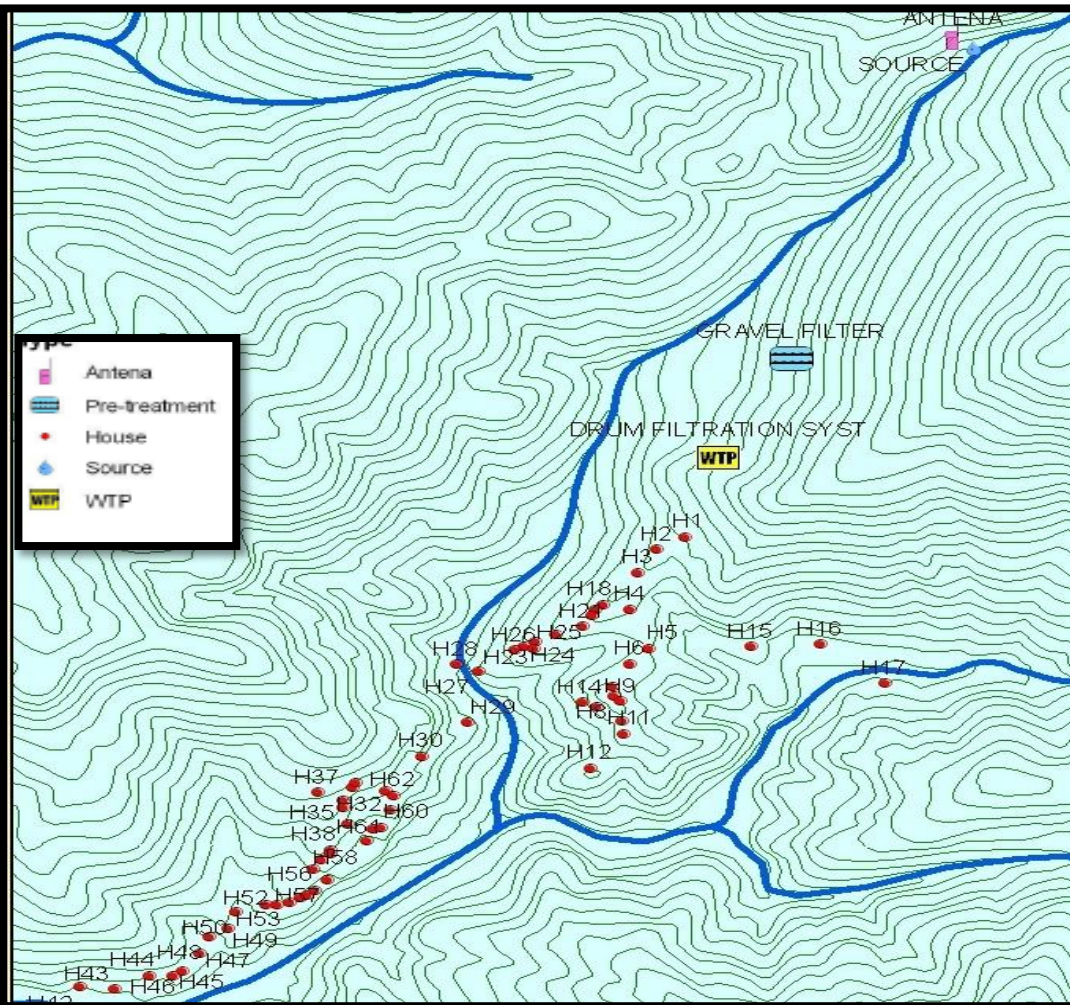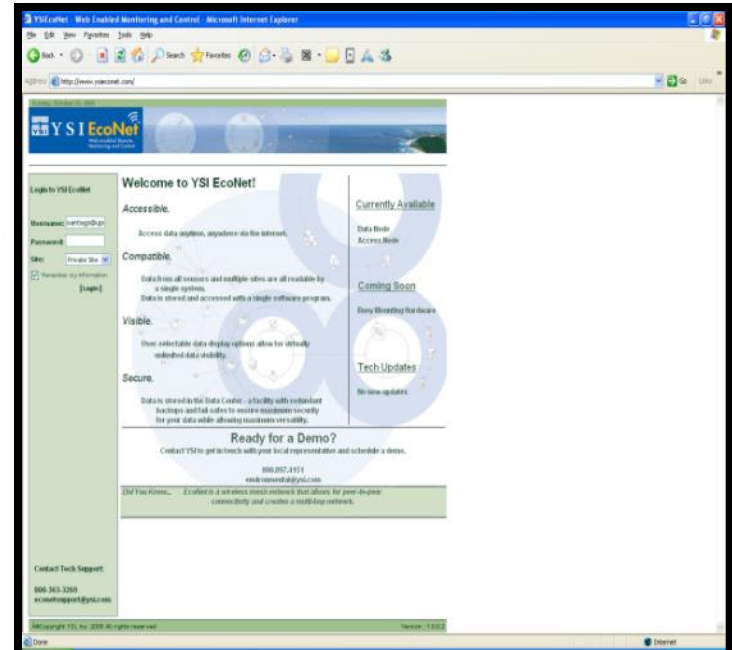

62 Houses
Approximately 240 residents
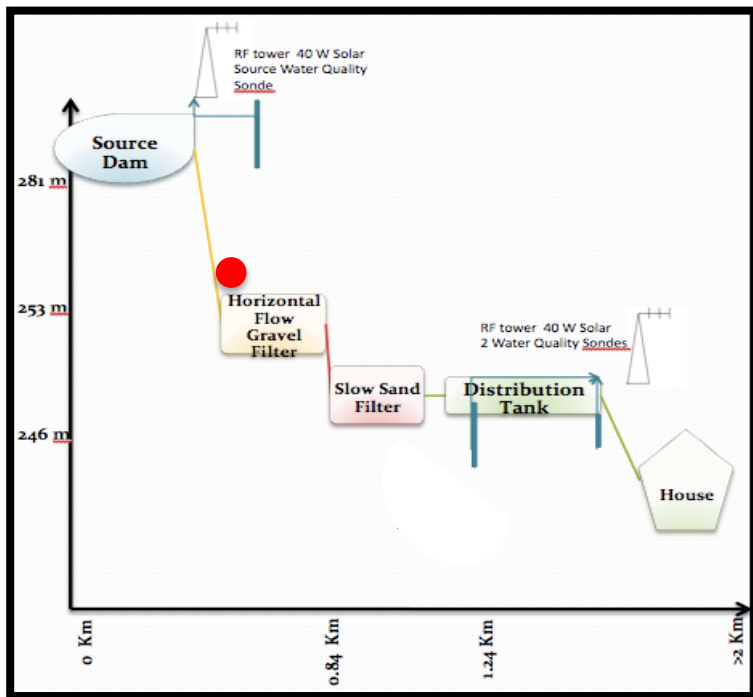
Hwang Water Quality Laboratory

Telemetry Monitoring, Site Maintenance, Community Connect

Hwang Water Quality Laboratory

Telemetry
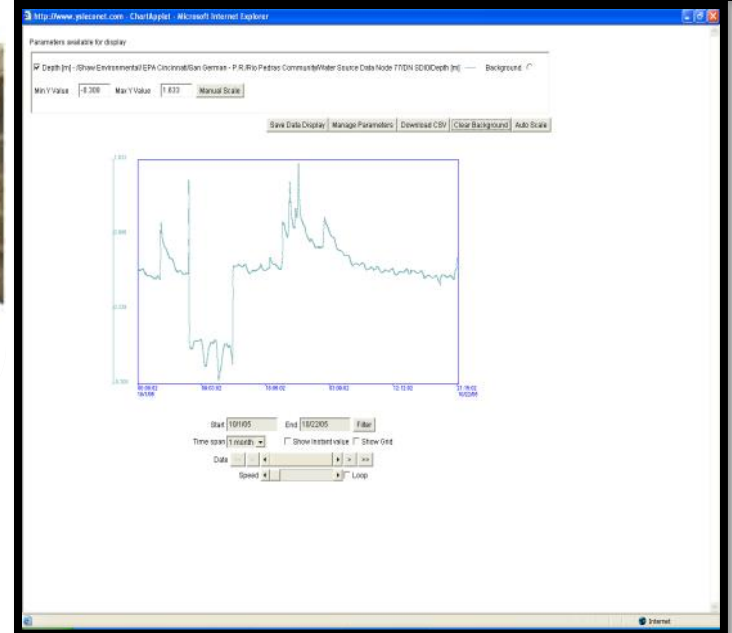
Water level, conductivity, DO, turbidity, Temp.

Lab-scale GS Filter
(Gravel Pre-filter + Sand Filter)

- Designed and operated in the same manner as the community's filtration/disinfection plant

GS Filter Performance

Parameter	Units	GS	GS with GAC[a]	GS with BAB[b]	USEPA Standards
pH		6.6	7.2	7.6	6-8
Turbidity	NTU	**3.33**	**3.67**	**4.39**	1
Turbidity Removal	%	44.5	44	55	-
Cl_2 spike	mg/L	26.72	24.97	13.4	-
Residual Cl_2	mg/L	**10.23**	**10.43**	**8.3**	4
Chloroform	ppb	37.25	BDL	BDL	80 (TTHMs)[c]
E. coli	CFU/100 mL	**3**	**0.5**	**0.5**	0
***E. coli* Removal**	%	99.9999975	99.9999986	99.99999987	-
Log removal		> 5	> 5	> 5	-

[a]GAC: Granular Activated Carbon
[b]BAB: Biopolymer Alginate Bead
[c]TTHMs: (Chloroform+Dibromochloromethane+Bromoform+Bromodichloromethane)

Hwang Water Quality Laboratory

EFFORT 3.
SOURCE WATER QUALITY MONITORING (2012-2014)

Source Water Quality (2012-2014)

Cain Alto River

pH, Temp. Conductivity, Turbidity, TDS, TOC, Total coliforms, *E. coli*, *Bacillus subtilis*

Hwang Water Quality Laboratory

Summary for pH
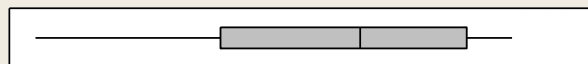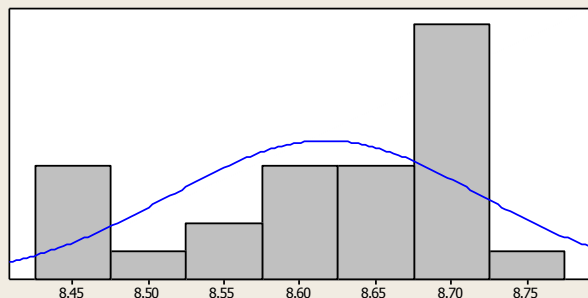
Anderson-Darling Normality Test

A-Squared	0.93
P-Value	0.016
Mean	8.6170
StDev	0.1022
Variance	0.0104
Skewness	-0.701794
Kurtosis	-0.762164
N	25
Minimum	8.4250
1st Quartile	8.5475
Median	8.6400
3rd Quartile	8.7100
Maximum	8.7400

95% Confidence Interval for Mean

8.5748   8.6592

95% Confidence Interval for Median

8.5840   8.7010

95% Confidence Interval for StDev

0.0798   0.1421

95% Confidence Intervals
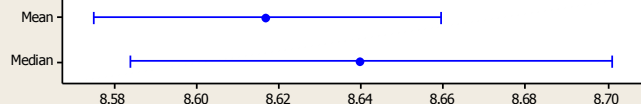
Summary for Conductivity
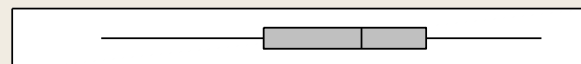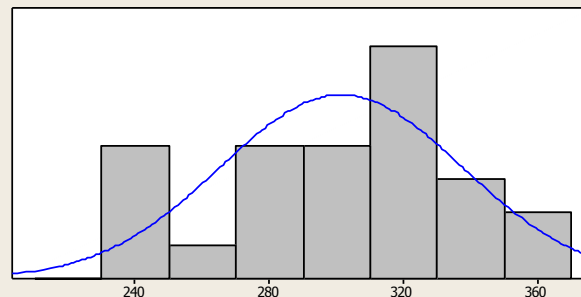
Anderson-Darling Normality Test

A-Squared	0.48
P-Value	0.211
Mean	301.40
StDev	36.07
Variance	1301.04
Skewness	-0.457048
Kurtosis	-0.678276
N	25
Minimum	230.00
1st Quartile	278.25
Median	307.50
3rd Quartile	326.75
Maximum	361.00

95% Confidence Interval for Mean

286.51   316.29

95% Confidence Interval for Median

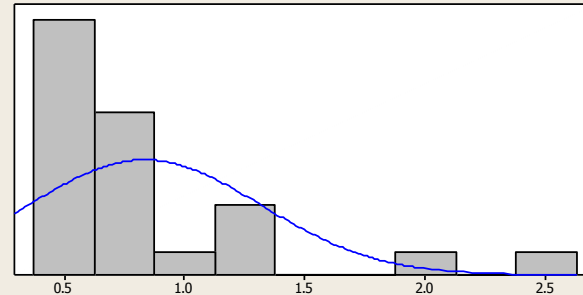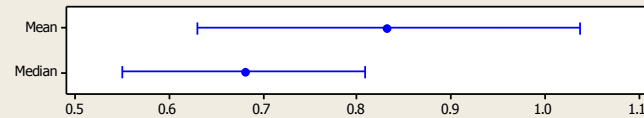281.99   322.50

95% Confidence Interval for StDev

28.16   50.18

95% Confidence Intervals
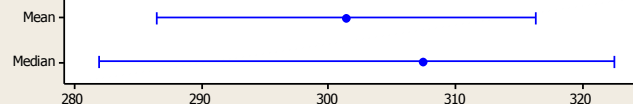
Hwang Water Quality Laboratory

Summary for Turbidity

Anderson-Darling Normality Test	
A-Squared	2.06
P-Value <	0.005
Mean	0.83292
StDev	0.48291
Variance	0.23321
Skewness	2.16019
Kurtosis	5.09600
N	24
Minimum	0.38000
1st Quartile	0.55000
Median	0.68250
3rd Quartile	1.04500
Maximum	2.45000

95% Confidence Interval for Mean
0.62900   1.03683
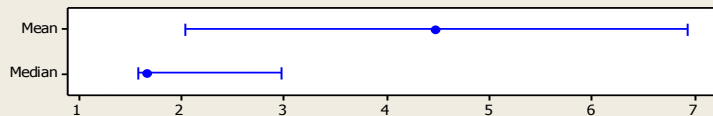95% Confidence Interval for Median
0.55000   0.80866
95% Confidence Interval for StDev
0.37533   0.67741

95% Confidence Intervals

Summary for TOC
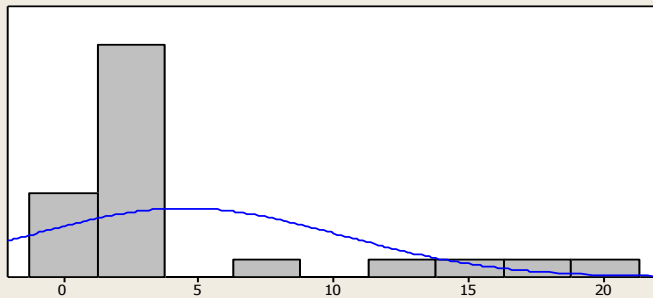
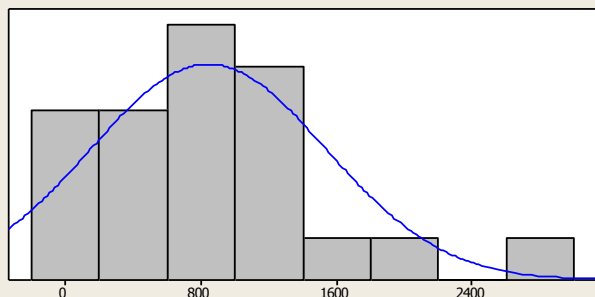| Anderson-Darling Normality Test	
A-Squared	3.72
P-Value <	0.005
Mean	4.4854
StDev	5.7788
Variance	33.3947
Skewness	1.81508
Kurtosis	1.97468
N	24
Minimum	0.3000
1st Quartile	1.3125
Median	1.6750
3rd Quartile	3.4625
Maximum	19.5500

95% Confidence Interval for Mean
2.0452   6.9256
95% Confidence Interval for Median
1.5827   2.9780
95% Confidence Interval for StDev
4.4914   8.1063

95% Confidence Intervals

Hwang Water Quality Laboratory

Summary for Total coliforms

Anderson-Darling Normality Test	
A-Squared	0.50
P-Value	0.182
Mean	843.77
StDev	693.28
Variance	480636.66
Skewness	1.21493
Kurtosis	2.13970
N	22
Minimum	11.00
1st Quartile	230.00
Median	775.00
3rd Quartile	1207.50
Maximum	2860.00

95% Confidence Interval for Mean
536.39   1151.16
95% Confidence Interval for Median
415.08   1092.46
95% Confidence Interval for StDev
533.38   990.74

95% Confidence Intervals
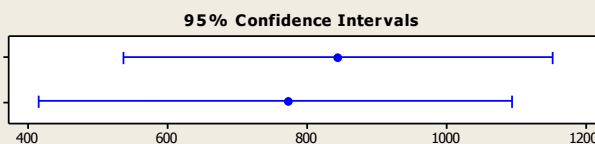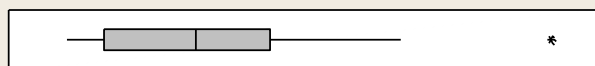
Summary for E.coli
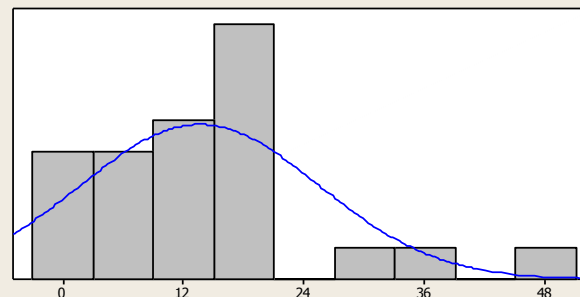
Anderson-Darling Normality Test	
A-Squared	1.08
P-Value	0.006
Mean	13.583
StDev	11.847
Variance	140.341
Skewness	1.51713
Kurtosis	3.01422
N	24
Minimum	0.000
1st Quartile	5.000
Median	12.500
3rd Quartile	16.750
Maximum	50.000

95% Confidence Interval for Mean
8.581   18.586
95% Confidence Interval for Median
5.827   16.000
95% Confidence Interval for StDev
9.207   16.618

95% Confidence Intervals
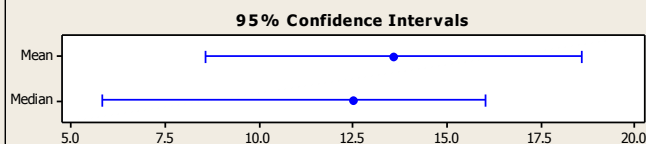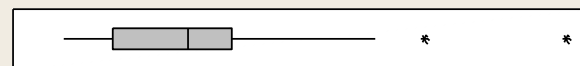
Summary for B. subtilis
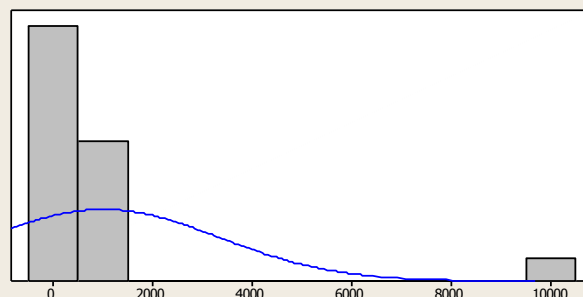
Anderson-Darling Normality Test	
A-Squared	4.33
P-Value <	0.005
Mean	1013.6
StDev	2327.0
Variance	5414734.7
Skewness	4.0390
Kurtosis	16.7631
N	18
Minimum	105.0
1st Quartile	150.0
Median	270.0
3rd Quartile	942.5
Maximum	10200.0

95% Confidence Interval for Mean
-143.6   2170.8
95% Confidence Interval for Median
155.2   843.0
95% Confidence Interval for StDev
1746.1   3488.4

95% Confidence Intervals

Hwang Water Quality Laboratory
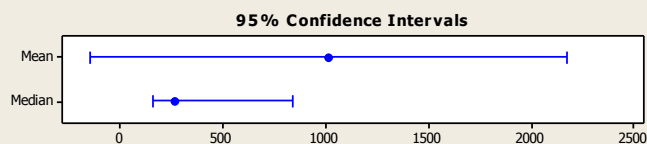
Statistical Correlation

	pH	Conductivity	Turbidity	TDS	TOC	Temperature	*E. coli*	Total coliforms
Conductivity	-0.216							
	0.3							
Turbidity	0.103	**-0.581**						
	0.633	**0.003**						
TDS	-0.188	**0.953**	**-0.438**					
	0.369	**0**	**0.032**					
TOC	-0.418	-0.063	0.101	-0.147				
	0.042	0.768	0.639	0.492				
Temperature	-0.128	-0.277	0.113	-0.391	**0.433**			
	0.542	0.181	0.6	0.053	**0.035**			
E. coli	0.312	**-0.692**	**0.451**	**-0.57**	-0.186	0.052		
	0.138	**0**	**0.027**	**0.004**	-0.385	0.809		
Total coliforms	-0.021	**-0.551**	0.236	**-0.507**	-0.008	0.322	**0.437**	
	0.927	**0.008**	0.29	**0.016**	0.973	0.144	**0.042**	
B. subtilis	0.232	**-0.556**	**0.72**	-0.45	-0.021	0.035	0.401	0.341
	0.355	**0.017**	**0.001**	0.061	0.934	0.89	0.099	0.167

Cell contents: Pearson correlation

P-value

Not Enough Water

Hwang Water Quality Laboratory

EFFORT 4.
SOLAR-POWERED DRUM FILTRATION

Solar-Powered Drum Filtration

Sand, d_{10}
　　　0.18 mm
　　　0.55 mm
　　　1.10 mm

Power
　　　Solar
　　　Hydraulic
　　　Gravitational

Hwang Water Quality Laboratory

Port	Water
1	Pre-filtered
2	Pre –chlorinated
3	Drums effluent
4	Post-chlorinated
5	Slow Sand Filtered Water
6	Backwash effluent

Pre-Chlorination

3- Drums Filtration

Post-Chlorination

Legend:

- Sampling Port

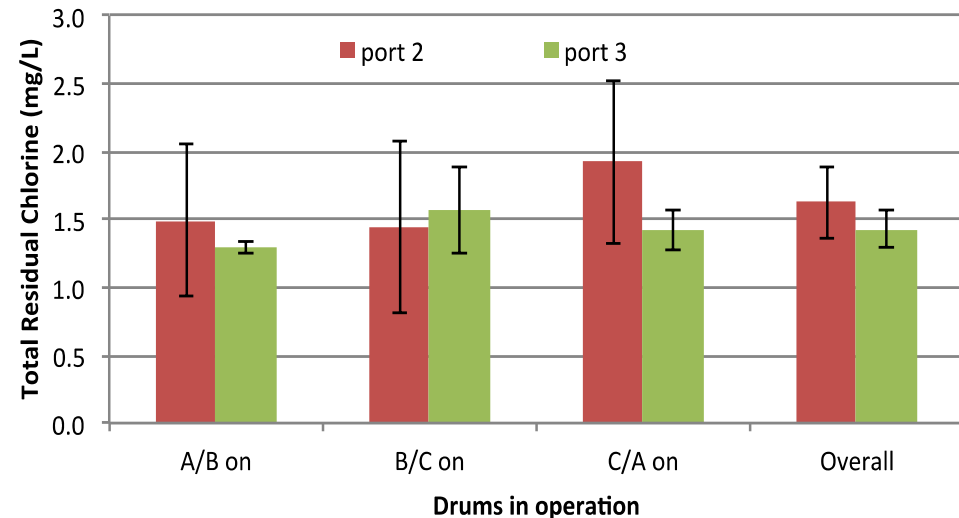- ½ inch pipe

- 2 inch Backwash pipe
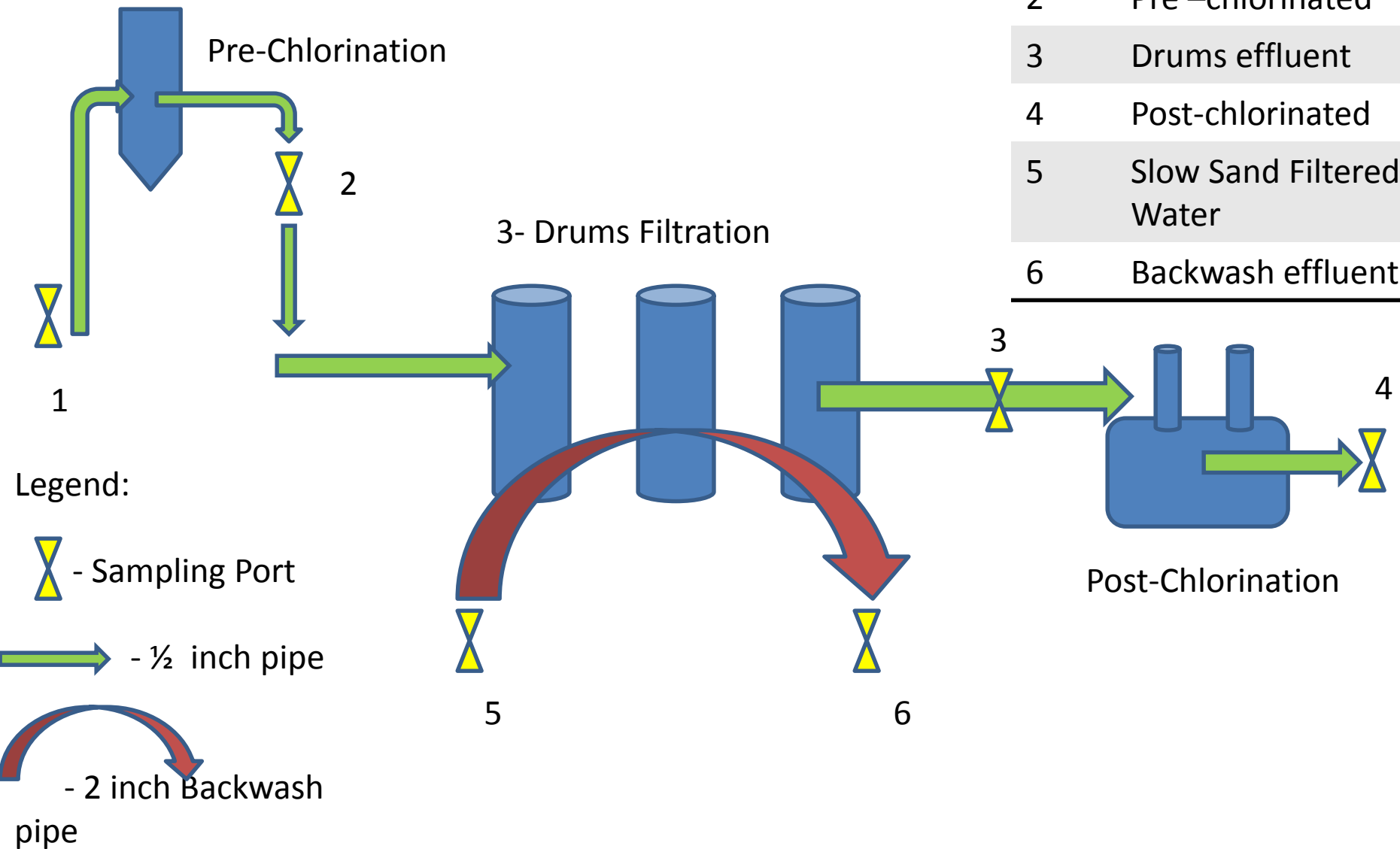
Fixing, Improving, and Testing
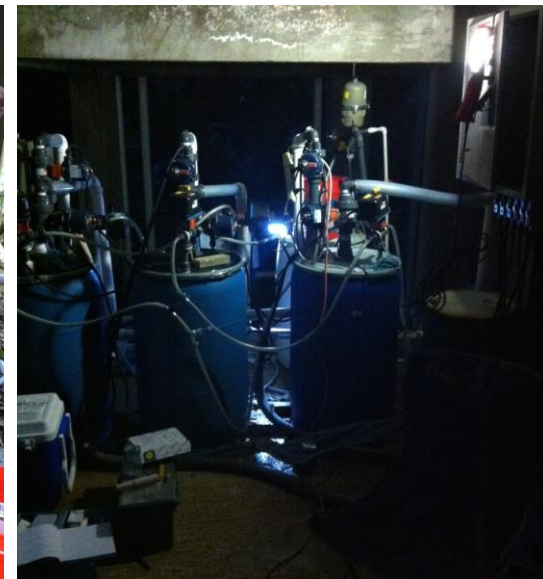
Drum Filtration Performance

pH
Turbidity
Conductivity
Chlorine

Heterotrophic bacteria
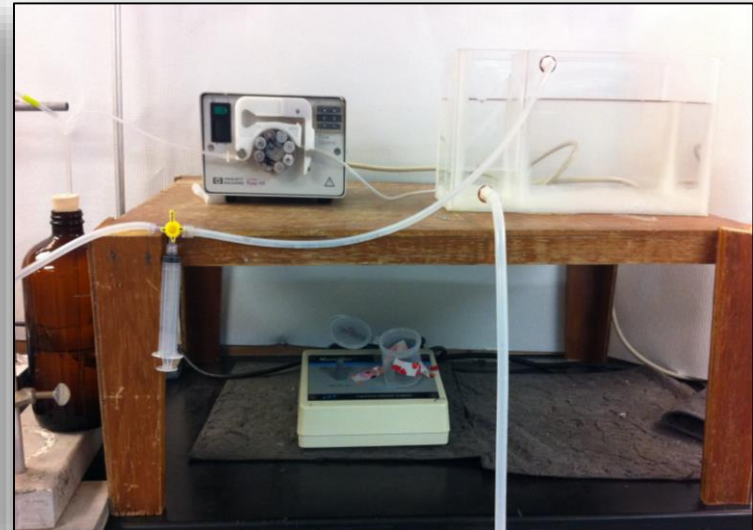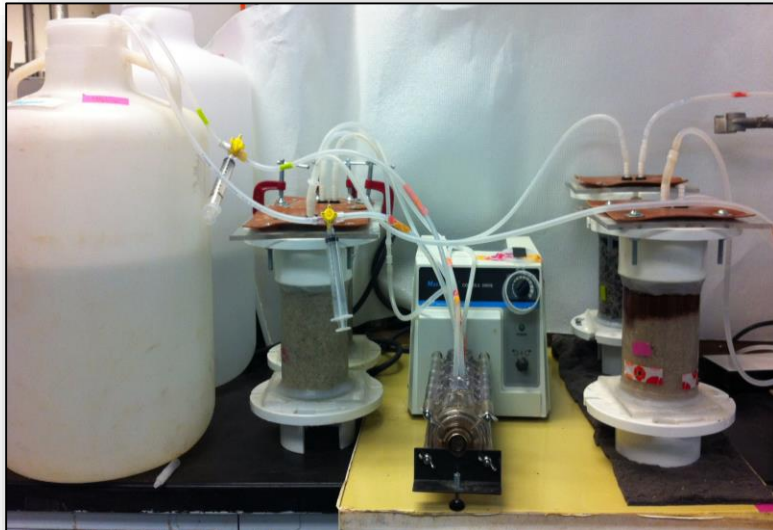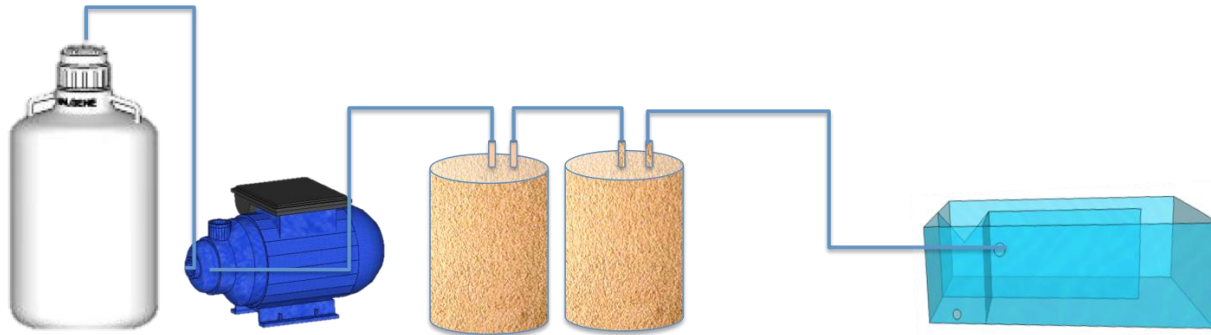Coliforms
Bacillus subtilis
MS2 Bacteriophage
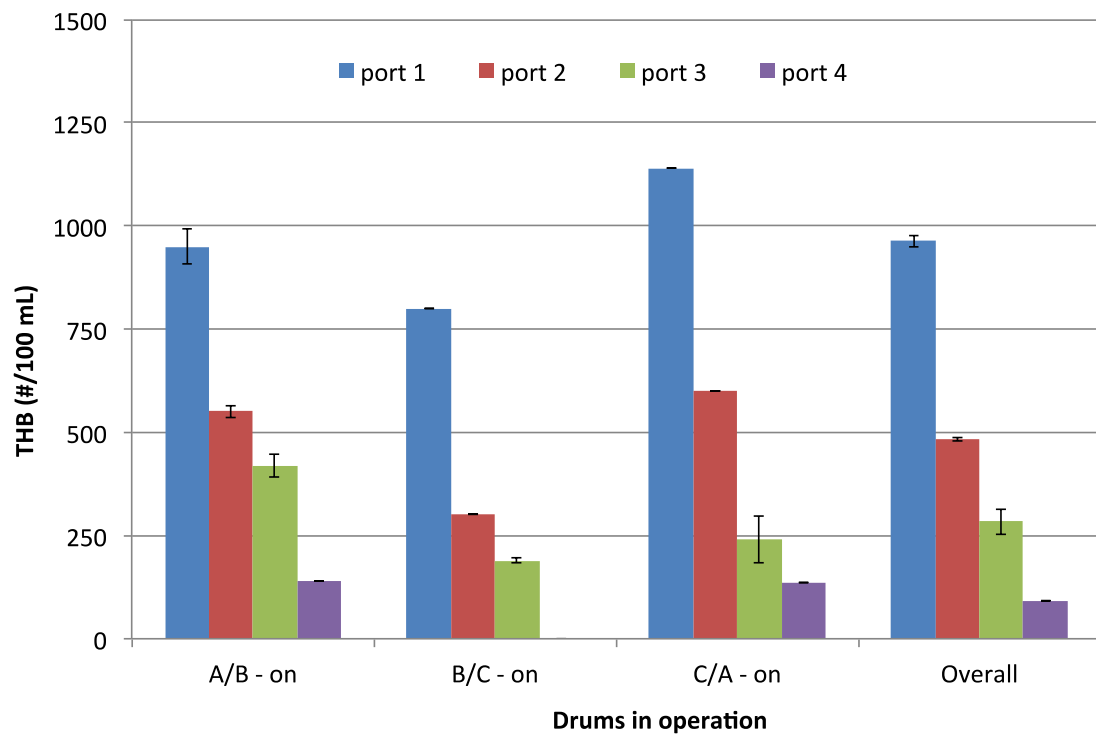
1 gallon per minute
Two drums in operation for 2 days 8 hrs
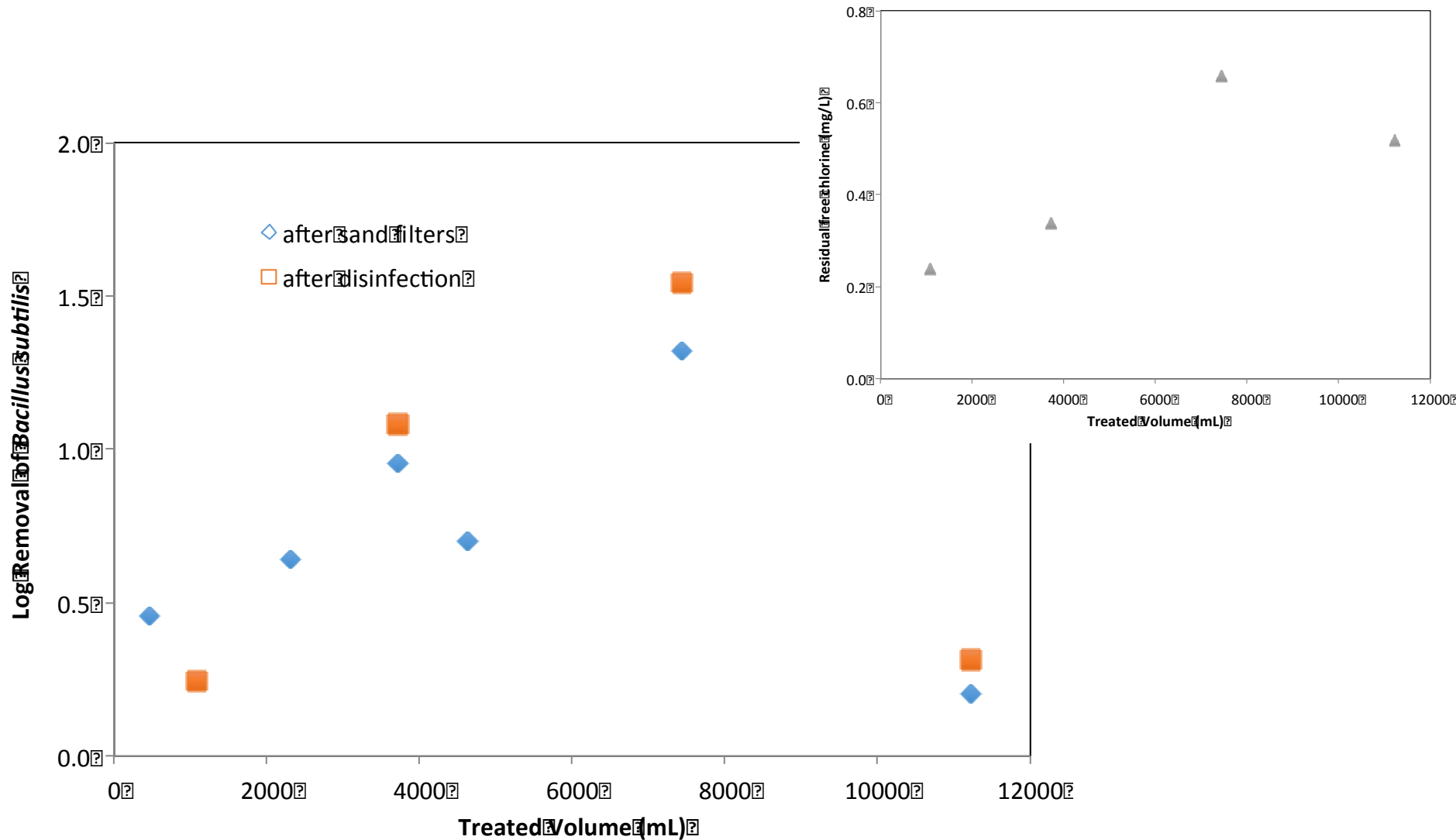One drum in backwash for 6 mins
   and then in standby

Hwang Water Quality Laboratory

Lab-scale SS Filter
(Sand Filter + Sand Filter)

- To support field-scale drum sand filtration / disinfection with a better process control

Bacillus subtilis Removal and Residual Free Chlorine of Lab scale SS Filtration and Disinfection

◇ after sand filters

□ after disinfection

Log Removal of *Bacillus subtilis*

Treated Volume (mL)

Residual free chlorine (mg/L)

Treated Volume (mL)

Hwang Water Quality Laboratory

ca. Feb 2008

ca. Mar 2009

ca. 2012

ca. Jun 2014

Hwang Water Quality Laboratory

Urgent Need of the Rio Piedras Community

- Shut-off valve
    when turbidity > 5 NTU
- To save the filtration systems

- Sonde at the intake
- Communication systems

For Rural Communities? By Rural Communities?

Currently working on the development of a system simpler and more appropriate for rural communities.

High Brains with Warm Hearts
for Rural Community Water Sustainability

Sangchul Hwang, PhD

Professor

Department of Civil Engineering

University of Puerto Rico at Mayagüez

sangchul.hwang@upr.edu

+1-787-832-4040 ext. 3454